PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

REC'D 08 MAR 2006
WIPO PCT

Applicant's or agent's file reference AIC-024-PCT2	**FOR FURTHER ACTION**	See Form PCT/IPEA/416
International application No. PCT/EP2004/013630	International filing date *(day/month/year)* 01.12.2004	Priority date *(day/month/year)* 01.12.2003
International Patent Classification (IPC) or national classification and IPC G10L19/02		
Applicant AIC et al		

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 10 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *sent to the applicant and to the International Bureau)* a total of 11 sheets, as follows:
      - ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      - ☐ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.

   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or tables related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

☒	Box No. I	Basis of the opinion
☒	Box No. II	Priority
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐	Box No. IV	Lack of unity of invention
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐	Box No. VI	Certain documents cited
☐	Box No. VII	Certain defects in the international application
☐	Box No. VIII	Certain observations on the international application

Date of submission of the demand 03.10.2005	Date of completion of this report 07.03.2006
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Dobler, E Telephone No. +49 89 2399-6048

Europäisches Patentamt • European Patent Office • Office européen des brevets

Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:
   - ☐ international search (under Rules 12.3 and 23.1(b))
   - ☐ publication of the international application (under Rule 12.4)
   - ☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

Description, Pages

1-27, 30-41	as originally filed
28, 29	received on 03.10.2005 with letter of 03.10.2005

Claims, Numbers

1-26	received on 03.10.2005 with letter of 03.10.2005

Drawings, Sheets

1/13-13/13	as originally filed

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing

3. ☐ The amendments have resulted in the cancellation of:
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

* *If item 4 applies, some or all of these sheets may be marked "superseded."*

Box No. II Priority

1. ☐ This report has been established as if no priority had been claimed due to the failure to furnish within the prescribed time limit the requested:
   - ☐ copy of the earlier application whose priority has been claimed (Rule 66.7(a)).
   - ☐ translation of the earlier application whose priority has been claimed (Rule 66.7(b)).
2. ☐ This report has been established as if no priority had been claimed due to the fact that the priority claim has been found invalid (Rule 64.1). Thus for the purposes of this report, the international filing date indicated above is considered to be the relevant date.
3. Additional observations, if necessary:

   see separate sheet

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-26
	No:	Claims	-
Inventive step (IS)	Yes:	Claims	3,5-12
	No:	Claims	1-2,4,13-26
Industrial applicability (IA)	Yes:	Claims	1-26
	No:	Claims	-

2. Citations and explanations (Rule 70.7):

   see separate sheet

1 Reference is made to the following documents (D1-D4):

D1: WO95/30983 (George, Smith)
D2: David P A M-S; Szczupak J: Refining the digital spectrum. IEEE 39th Midwest symposium on Circuits and Systems, Ames, IA, USA 18-21 Aug. 1996. Vol. 2, pages 767-770. New York, NY, USA,IEEE, US, XP010222730.
D3: Wim D'haes: A highly optimized nonlinear least squares technique for sinusoidal analysis: From 'O(K^2N) to 'O(N log(N)). Preprint on the 116th Audio Engineering Society (AES) Convention, 8-11 May 2004, Berlin, Germany, pages 1-12.
D4: Mength: "The discrete Fourier Transform". Handout at Stanford University, 09-02-2003. XP2275706.

2 PRIORITY

The International Search Report contains a P-document (D3), consequently the validity of the right to priority should be examined (see the PCT Guidelines, 6.06 (I)). Priority is claimed to the document BEW0300207 (further referred to as the *priority document*).

The right to priority is valid for claims 1,2 and 4 only, for the following reasons:

2.1 The present application discloses "a nonstationary nonharmonic model", which is not disclosed by the priority document (*renders the priority invalid for claims 3, 5 and all claims dependent thereon)*

2.2 The present application discloses that "the parameter λ_1 allows to switch between different optimization methods and the parameter λ_2 regularizes the system matrix", which is not disclosed by the priority document (*renders the priority invalid for claims 8-9 and all claims dependent thereon)*

2.3 The present application discloses "a step of computing instantaneous frequencies and instantaneous amplitudes", which is not disclosed by the priority document (*renders the priority invalid for claim 11 and all claims dependent thereon)*

2.4 The present application discloses "a step of computing damping factor", which is not

disclosed by the priority document (*renders the priority invalid for claim 12 and all claims dependent thereon)*

2.5 It should be noted that the right for priority is valid for the *subject-matter* of claims 6,7,10,13,14-26 as long as they are dependent on any of claims 1,2 or 4 only, but not for claims 6,7,10,13,14-26 as such (since they are also dependent on claims for which priority is not valid).

3 CLARITY

The application does not meet the requirements of Article 6 PCT, because claims 2-9, 13 are not clear.

3.1 Claims 2,3,5,7 lack the definition of w_n, therefore causing lack of clarity. This problem could be remedied by defining w_n as the window of claim 1 (*based on description page 2, line 5)*

3.2 Claim 6 claims "determining the number of relevant diagonal bands D". However, it is not clear where these diagonal bands can be found. This problem could be remedied by including the subject-matter on description *page 35, lines 11 to 12*.

3.3 Claims 8-9 lack the definition of the "residual spectrum R_m", therefore causing lack of clarity. This problem could be remedied by including the subject-matter on description *page 17, line 22*.

3.4 Claim 13 lacks the definition of N' and $w^{N'}_{M'}$, therefore causing lack of clarity. This problem could be remedied by including the subject-matter on description *page 33, lines 22 to 25*.

3.5 The terms *close* and *relevant* used in claim 6 are vague and unclear and leave the reader in doubt as to the meaning of the technical features to which they refer, thereby rendering the definition of the subject-matter of said claim unclear, Article 6 PCT.

3.6 Some of the dependent claims contain features which are not present in every claim on which they are based, therefore causing lack of clarity. The problematic claims are:

Claim 4 when dependent on claim 1, referring to "the stationary nonharmonic model" and to the "harmonic model".
Claim 7 when dependent on claim 1, referring to "the stationary complex amplitudes".
Claim 8 when dependent on claim 1, referring to "the stationary nonharmonic model".
Claim 9 when dependent on claim 1, referring to "harmonic signal model".

These problems could be remedied by removing references to claims which do not contain the claimed feature.

3.7 Throughout the set of the claims references are made to equations in the description. According to Rule 6.2(a) PCT, claims should not contain such references except where absolutely necessary, which is not the case here (since the claims contain the equations as well).
It is suggested that the references to equations be deleted or be put into parentheses.

3.8 Despite the clarity problems mentioned in 3.1-3.7, an examination has been carried out in the sense of the above considered corrections.

4.1 The present application does not meet the criteria of Article 33(1) PCT, because the subject-matter of claim 1 does not involve an inventive step in the sense of Article 33(3) PCT.

The document D1 is regarded as being the closest prior art to the subject-matter of claim 1, and discloses (the references in parentheses applying to this document):

"A method for modelling, analyzing and/or synthesizing, a windowed signal (*page 4, lines 15-23; page 10, lines 30-31 in D1*),
by computing the frequencies and complex amplitudes from the signal using a nonlinear least squares method" (*page 10, line 3 - page 12, line 10 in D1*)

Document D1 also discloses the problem that sinusoidal modelling is computationally expensive (*page 3, line 35 - page 4, line 11 in D1*).
The problem to be solved with regard to D1 can therefore be formulated as to make the calculation of the model parameters computationally less expensive.

The skilled person desiring to solve this problem would search further in the prior art and he would find document D2. D2 discloses:

"the computational complexity is reduced by taking into account the bandlimited property of the window." (*page 770, right-hand column, lines 15-24 in D2*)

The skilled person would combine the documents D1 and D2 since both deal with the parameter estimation of a sinusoidal model, therefore obtaining the subject-matter of present claim 1 in an obvious way, which therefore does not involve an inventive step, hence does not meet the criteria of Art. 33(3) PCT.

In his letter of reply dated 3.10.2005, the Applicant argues that the application "allows the computation of all amplitudes simultaneously" by "solving Eq. (19) by an adapted gaussian elimination routine", which features are not present in D1 nor in D2. However, these features are also not present in claim 1. Therefore, they cannot be taken into account when examining novelty or inventive activity in claim 1.
The examiner would like to point out that, for example, the subject-matter of equation (19) is claimed by present dependent claim 7, not by present independent claim 1.

4.2 Dependent claims 2,4,13 do not contain any features which, in combination with claim 1 (claims 2 and 13) or in combination with claim 2 (claim 4) to which they refer, meet the requirements of the PCT in respect of inventive step, the reasons being as follows:

D1 discloses:
[claim 2]: "a stationary nonharmonic signal model *according to Equ. (2)*" (*page 9, equation (10) in D1*)

D2 discloses:

[claim 4]: "computation of the spectrum as a linear combination of the frequency responses of the window according to equ. (11) or (12)" (*equation (2) in D2*)

D4 discloses:

[claim 13]: "the frequency response of the window with length M zero padded up to a length N is computed by using a scaled table look-up according to Eq. (82). (*Section "Zero padding" on pages 6-7 of D4, where D4 represents general background knowledge*)"

Consequently the obvious combination of D1 and D2 discloses the subject-matter of present claims 2,4 and 13, which therefore do not meet the criteria of Art. 33(3) PCT.

4.3 The combination of the features of dependent claims 3,5-12 is neither known from, nor rendered obvious by, the available prior art. A brief indication of the subject-matter which renders claims 3,5-12 new and inventive is as follows (for the sake of compactness, subject-matter in the equations are indicated by the number of the equation only):

[claim 3]: "a nonstationary harmonic model according to equ. (4)"

[claim 5]: "computation of the spectrum as a linear combination of the frequency responses of the window according to equ. (13)"

[claim 6]: "determining the number of relevant diagonal bands D" of the matrix B

[claim 7]: "computing the stationary complex amplitudes, by solving the equations in equ. (19)"

[claim 8]: "optimizing the frequencies for the stationary nonharmonic model by solving equation (34)"

[claim 9]: "computing the optimization step by solving equ. (48) by using equ. (49)"

[claim 10]: "computing the polynomial complex amplitudes by solving equ. (55)"

[claim 11]: "computing instantaneous frequencies and instantaneous amplitudes according to equ. (69)"

[claim 12]: "computing damping factor according to equ. (78)"

4.4 Dependent claims 14-16, 19-22 do not contain any features which, in combination with claims 1,2,4 or 13, to which they refer, meet the requirements of the PCT in respect of inventive step, the reasons being as follows:

[claim 14], when dependent on any of claims 1,2,4,13: "Apparatus adapted to carry out each and every step according to any of claim 1-13" (*The methods of claims 1,2,4,13 are not inventive, hence neither is an apparatus implementing them*)

[claims 15-16], when dependent on any of claims 1,2,4,13: "for accurate pitch estimation (*page 5, lines 11 to 12 in D1*)"

[claims 19-20], when dependent on any of claims 1,2,4,13: "for parametric/sinusoidal audio coders" (*Fig. 1, 17, 28 in D1*)

[claims 21-22], when dependent on any of claims 1,2,4,13: "for audio effects" (*claim 3 in D1*)

4.5 Claims 17-18, 23-26 do not meet the requirements of Article 6 PCT in that the matter for which protection is sought is not clearly defined. The claims attempt to define the subject-matter in terms of the result to be achieved, which merely amounts to a statement of the underlying problem, without providing the technical features necessary for achieving this result.

5.1 Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D2 and D3 is not mentioned in the description, nor are these documents identified therein.

from which follows that the expressions of Eq. (56) can be transformed to

$$
\begin{aligned}
B^{1,1}_{qK+l,pK+k} &= \frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{-q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k-\omega_l} \\
B^{1,2}_{qK+l,pK+k} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k+\omega_l} - (-1)^{q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k-\omega_l} \\
B^{2,1}_{qK+l,pK+k} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k-\omega_l} \\
B^{2,2}_{qK+l,pK+k} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{-q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k-\omega_l} \\
C^{1}_{qK+l} &= \Re\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m \frac{\partial^q}{\partial m^q} W(m+\omega_l)\right) \\
C^{2}_{qK+l} &= -\Im\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m \frac{\partial^q}{\partial m^q} W(m+\omega_l)\right) \\
A^{1}_{pK+k} &= A^{r}_{k,p} \\
A^{2}_{pK+k} &= A^{i}_{k,p}
\end{aligned}
\qquad (59)
$$

EPO -DG 1

07. 10. 2005

116

The vectors $\mathbf{C}$ and matrices $\mathbf{B}$ are now expressed in terms of the frequency response of the windows and the square window respectively. Each (p, q)-couple denotes a submatrix of the matrices of size $K \times K$. From the bandlimited property of $\Re[Y(m)]$ and its derivatives follows that these submatrices of $\mathbf{B}^{1,1}$ and $\mathbf{B}^{2,2}$ are band diagonal. In an analogue manner, since $\Im[Y(m)]$ and its derivatives always yield zero, the submatrices $\mathbf{B}^{1,2}$ and $\mathbf{B}^{2,1}$ contain only zeros. This structure is depicted at the top of Figure 10.

The upper left and lower right kwadrants contain band diagonal submatrices for each (p, q)-couple. This implies that all relevant values are stored at positions defined by a quadruple (l, q, k, p) for which the following conditions hold:

$$
\begin{aligned}
-D \le k - l &\le D \\
0 \le p &\le P-1 \\
0 \le q &\le P-1
\end{aligned}
\qquad (60)
$$

The inequalities given in Eq. (60) can be transformed to

$$
\begin{aligned}
-DP \le (k-l)P &\le DP \\
0 \le p &\le P-1 \\
-(P-1) \le -q &\le 0
\end{aligned}
\qquad (61)
$$

from which follows that

$$-(D+1)P+1 \leq (kP+p)-(lP+q) \leq (D+1)P-1 \tag{62}$$

By inverting the indexation order, i.e. using $(kP+p, lP+q)$ instead of $(pK+k, qK+l)$, one obtains for the row index $kP+p$ and for the column index $lP+q$. Since their difference denotes the index of the diagonal, it follows from Eq. (62) that all relevant values lie around the main diagonal. This is illustrated by the lower part of figure 10. A a result, the definition of the system of equations after inversion of the indexation becomes

$$\begin{aligned}
B^{1,1}_{lP+q,kP+p} &= \frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{-q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k-\omega_l}\\
B^{1,2}_{lP+q,kP+p} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k+\omega_l} - (-1)^{q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k-\omega_l}\\
B^{2,1}_{lP+q,kP+p} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k-\omega_l}\\
B^{2,2}_{lP+q,kP+p} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{-q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k-\omega_l}\\
C^{1}_{lP+q} &= \Re\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m \frac{\partial^q}{\partial m^q}W(m+\omega_l)\right)\\
C^{2}_{lP+q} &= -\Im\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m \frac{\partial^q}{\partial m^q}W(m+\omega_l)\right)\\
A^{1}_{kP+p} &= A^{r}_{k,p}\\
A^{2}_{kP+p} &= A^{i}_{k,p}
\end{aligned} \tag{63}$$

By using a look-up table for each derivative of the frequency response each element can be computed in constant time. Since $\mathbf{B}^{1,1}$ and $\mathbf{B}^{2,2}$ are band diagonal they can be stored in a more compact form containing only the relevant diagonal bands, yielding

$$\begin{aligned}
\overleftarrow{B^{1,1}}_{lP+q,kP+p} = B^{1,1}_{lP+q,lP+q+kP+p-(D+1)P+1} = B^{1,1}_{lP+q,(k+l-D)P+(p+q-P+1)}\\
\overleftarrow{B^{2,2}}_{lP+q,kP+p} = B^{2,2}_{lP+q,lP+q+kP+p-(D+1)P+1} = B^{2,2}_{lP+q,(k+l-D)P+(p+q-P+1)}
\end{aligned} \tag{64}$$

with p and q ranging from 0 to $P-1$, l ranging from 0 to $K-1$, and k from 0 to $2D$.

Conclusion

A least squares method is derived which allows to analyse non stationary sinusoidal components defined by Eq.(50). This model for a windowed signal of length N, consists of K sinusoidal components with complex polynomial component of order P. When the equations are solved in the time domain the computation of the system matrix has a complexity

CLAIMS (Retyped)

1. A method for modelling, analyzing and/or synthesizing, a windowed signal, by computing the frequencies and complex amplitudes from the signal using a nonlinear least squares method, whereby the computational complexity is reduced by taking into account the bandlimited property of the window.

2. A method according to claim 1 using a stationary nonharmonic signal model according to Eq. (2), which is a model with K stationary components where each component is characterized by its complex amplitude A_k and frequency ω_k

$$\tilde{x}_n = \Re\left[w_n \sum_{k=0}^{K-1} A_k \exp(-2\pi i \omega_k \tfrac{n-n_0}{N})\right] \qquad (2)$$

or a harmonic signal model according to Eq. (3), which is a model with S quasi-periodic stationary sound sources with a fundamental frequency ω_k, each consisting of S_k sinusoidal components with frequencies that are integer multiples of ω_k, and in which the complex amplitude of the pth component of the kth source is denoted $A_{k,p}$

$$\tilde{x}_n = \Re\left[w_n \sum_{k=0}^{S-1} \sum_{p=0}^{S_k-1} A_{k,p} \exp(-2\pi i p \omega_k \tfrac{n-n_0}{N})\right] \qquad (3)$$

3. A method according to claim 1 using a nonstationary nonharmonic model according to Eq. (4), which is a model with K nonstationary sinusoidal components which have independent frequencies ω_k, and in which the amplitudes $A_{k,p}$ denote the p-th order of the k-th sinusoid

$$\tilde{x}_n = \Re\left[w_n \sum_{k=0}^{K-1} \sum_{p=0}^{P-1} A_{k,p} (-2\pi i \tfrac{n-n_0}{N})^p \exp(-2\pi i \omega_k \tfrac{n-n_0}{N})\right] \qquad (4)$$

4. A method according to claim 1 or 2, comprising the computation of the spectrum as a linear combination of the frequency responses of the window according to Eq. (11) for the stationary nonharmonic model,

$$\tilde{X}_m = \sum_{k=0}^{K-1} A_k W(m + \omega_k) \qquad (11)$$

or Eq. (12) of the harmonic model

$$\tilde{X}_m = \sum_{k=0}^{S-1} \sum_{p=0}^{S_k-1} A_{k,p} W(m + p\omega_k) \qquad (12)$$

where the fourier transform of a complex signal results in a spectrum $\tilde{X}_m$, where $W(m)$ denotes the discrete time fourier transform of w_n and whereby only the main lobes of the responses are computed by using look-up tables

5. A method according to claim 3, comprising the computation of the spectrum as a linear combination of the frequency responses of the window according to Eq. (13) for the nonstationary model,

$$\begin{aligned}
\tilde{X}_m &= \sum_{n=0}^{N-1} w_n \left[\sum_{k=0}^{K-1} \sum_{p=0}^{P-1} A_{k,p} (-2\pi i \tfrac{n-n_0}{N})^p \exp(-2\pi i \omega_k \tfrac{n-n_0}{N}) \right] \exp(-2\pi i m \tfrac{n-n_0}{N}) \\
&= \sum_{k=0}^{K-1} \sum_{p=0}^{P-1} A_{k,p} \left[\sum_{n=0}^{N-1} w_n (-2\pi i \tfrac{n-n_0}{N})^p \exp(-2\pi i (\omega_k + m) \tfrac{n-n_0}{N}) \right] \\
&= \sum_{k=0}^{K-1} \sum_{p=0}^{P-1} A_{k,p} \frac{\partial^p}{\partial m^p} W(\omega_k + m) \qquad (13)
\end{aligned}$$

where the fourier transform of a complex signal results in a spectrum $\tilde{X}_m$, where $W(m)$ denotes the discrete time fourier transform of w_n whereby only the main lobes of the responses are computed by using look-up tables.

6. A method according any of claim 1 to 5, comprising a pre-processing step which comprises: sorting the frequencies, eliminating frequencies which are close to one another and determining the number of relevant diagonal bands D.

7. A method according any of claim 1 to 6, comprising the step of computing the stationary complex amplitudes, by solving the equations given in Eq. (19),

$$\begin{bmatrix} \mathbf{B}^{1,1} & \mathbf{B}^{1,2} \\ \mathbf{B}^{2,1} & \mathbf{B}^{2,2} \end{bmatrix} \begin{bmatrix} \mathbf{A}^r \\ \mathbf{A}^i \end{bmatrix} = \begin{bmatrix} \mathbf{C}^1 \\ \mathbf{C}^2 \end{bmatrix} \qquad (19)$$

where

$$\begin{aligned}
B_{l,k}^{1,1} &= \sum_{n=0}^{N-1} w_n^2 \cos(2\pi\omega_k \tfrac{n-n_0}{N}) \cos(2\pi\omega_l \tfrac{n-n_0}{N}) \\
B_{l,k}^{1,2} &= \sum_{n=0}^{N-1} w_n^2 \sin(2\pi\omega_k \tfrac{n-n_0}{N}) \cos(2\pi\omega_l \tfrac{n-n_0}{N}) \\
B_{l,k}^{2,1} &= \sum_{n=0}^{N-1} w_n^2 \cos(2\pi\omega_k \tfrac{n-n_0}{N}) \sin(2\pi\omega_l \tfrac{n-n_0}{N}) \\
B_{l,k}^{2,2} &= \sum_{n=0}^{N-1} w_n^2 \sin(2\pi\omega_k \tfrac{n-n_0}{N}) \sin(2\pi\omega_l \tfrac{n-n_0}{N}) \\
C_l^1 &= \sum_{n=0}^{N-1} x_n w_n \cos(2\pi\omega_l \tfrac{n-n_0}{N}) \\
C_l^2 &= \sum_{n=0}^{N-1} x_n w_n \sin(2\pi\omega_l \tfrac{n-n_0}{N})
\end{aligned}$$

using Eq. (20)

$$\begin{aligned}
B_{l,k}^{1,1} &= \frac{1}{2}\Re(Y(\omega_k+\omega_l)) + \frac{1}{2}\Re(Y(\omega_k-\omega_l)) \\
B_{l,k}^{1,2} &= -\frac{1}{2}\Im(Y(\omega_k+\omega_l)) - \frac{1}{2}\Im(Y(\omega_k-\omega_l)) \\
B_{l,k}^{2,1} &= -\frac{1}{2}\Im(Y(\omega_k+\omega_l)) + \frac{1}{2}\Im(Y(\omega_k-\omega_l)) \\
B_{l,k}^{2,2} &= -\frac{1}{2}\Re(Y(\omega_k+\omega_l)) + \frac{1}{2}\Re(Y(\omega_k-\omega_l)) \\
C_l^1 &= \Re\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m W(m+\omega_l)\right) \\
C_l^2 &= -\Im\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m W(m+\omega_l)\right) \qquad (20)
\end{aligned}$$

such that only the elements around the diagonal of $\mathbb{B}$ are taken into account, whereby a shifted form $\overleftarrow{\mathrm{B}}$ is computed containing only D diagonal bands of $\mathbb{B}$ according to Eq. (27)

$$\begin{aligned}
\overleftarrow{B^{1,1}}_{l,k} &= B_{l,l+k-D}^{1,1} \\
\overleftarrow{B^{2,2}}_{l,k} &= B_{l,l+k-D}^{2,2} \qquad (27)
\end{aligned}$$

and Eq. (20), whereby the computation of the Eq. (20) requires the computation of the frequency response of the window and the square window denoted by *W(m)* and *Y(m)* respectively, and solving equation given by Eq. (19) directly from $\overleftarrow{\mathbf{B}}$ and $\mathbf{C}$ in Eq. (28)

$$\begin{aligned} \mathbf{A}^{r} &= SOLVE(\overleftarrow{\mathbf{B}^{1,1}}, \mathbf{C}^{1}) \\ \mathbf{A}^{i} &= SOLVE(\overleftarrow{\mathbf{B}^{2,2}}, \mathbf{C}^{2}) \end{aligned} \tag{28}$$

by an adapted gaussian elimination procedure.

8. A method according to any of claim 1, 2, 4, 6 and 7, further comprising the step of optimizing the frequencies for the stationary nonharmonic model by solving the equation given in Eq. (34)

$$\mathbf{H}\Delta\omega = \mathbf{h} \tag{34}$$

, using Eq. (42)

$$\begin{aligned} \Delta\omega_l &= \hat{\omega}_l - \omega_l \\ h_l &= -\frac{2}{N}\Re\left(A_l \sum_{m=0}^{N-1} R_m W'(\hat{\omega}_l - m))\right) \\ H_{lk} &= \Re(A_k A_l Y''(\hat{\omega}_k + \hat{\omega}_l)) - \Re(A_k A_l^{*} Y''(\hat{\omega}_k - \hat{\omega}_l)) \\ &\quad -\lambda_1 \delta_{kl} \frac{2}{N}\Re\left(A_l \sum_{m=0}^{N-1} R_m W''(\hat{\omega}_l - m)\right) + \delta_{kl}\lambda_2 \end{aligned} \tag{42}$$

such that only elements around the diagonal of $\mathbf{H}$ are taken into account, whereby a shifted form $\overleftarrow{\mathbf{H}}$ is computed containing only D diagonal bands according to Eq. (36)

$$\overleftarrow{H}_{lk} = H_{l,l+k-D} \tag{36}$$

and Eq. (42), whereby the gradient h is computed from the residual spectrum R_m, amplitude A_l and frequencies ω_l, and requires the computation of derivative of the frequency response of the window *W'(m)*, whereby the first term of $\mathbf{H}$ requires the computation of the second derivative of the frequency response of the square window denoted *Y''(m)*, whereby the second term of $\mathbf{H}$ is computed from the residual spectrum *Rm*, amplitude A_l and frequencies ω_l, and requires the computation of the second derivative of the frequency response *W''(m)*, whereby the parameter λ_1 allows to switch

between different optimization methods and the parameter λ_2 regularizes the system matrix, and computing the optimization step by solving the system of equations directly on $\overleftarrow{\mathbf{H}}$ and $\mathbf{h}$ according to Eq. (37)

$$\Delta\bar{\omega} = SOLVE(\overleftarrow{\mathbf{H}}, \mathrm{h}) \qquad (37)$$

by an adapted gaussian elimination procedure.

9. A method according to any of claim 1, 2, 4, 6 and 7, further comprising the step of optimization the frequencies for the harmonic signal model, by computing the optimization step solving Eq. (48) using Eq. (49),

$$\mathrm{H}\Delta\omega = \mathrm{h} \qquad (48)$$

with

$$\begin{aligned}
\Delta\omega_l &= \hat{\omega}_l - \omega_l \\
h_l &= -\frac{2}{N}\sum_{q=1}^{S_l-1}\Re\left(\sum_{m=0}^{N-1} R_m q A_{l,q} W'(q\omega_l - m)\right) \\
H_{l,k} &= \sum_{q=1}^{S-1}\left[\sum_{r=1}^{r_{max,1}} qr\Re(A_{p,q}A_{l,r}Y''(q\omega_p + r\omega_l)\right. \\
&\quad + \sum_{r=r_{min,2}}^{r_{max,2}} qr\Re(A_{p,q}A_{l,r}Y''(q\omega_p + r\omega_l) \\
&\quad \left. - \sum_{r=r_{min,3}}^{r_{max,3}} qr\Re(A_{p,q}A^*_{l,r}Y''(q\omega_p - r\omega_l)\right] \\
&\quad -\lambda_1\delta_{lp}\frac{2}{N}\Re\left(\sum_{q=1}^{S_l-1}\sum_{m=0}^{N-1} R_m q^2 A_{p,q} W''(q\omega_p - m)\right) + \delta_{lp}\lambda_2
\end{aligned} \qquad (49)$$

whereby the gradient $\mathbf{h}$ is computed from the residual spectrum R_m, amplitude $\bar{A}_l$ and frequencies ω_l, and requires the computation of derivative of the frequency response of the window $W'(m)$, whereby the first term of $\mathbf{H}$ requires the computation of the second derivative of the frequency response of the square window denoted $Y''(m)$, whereby the second term of $\mathbf{H}$ is computed from the residual spectrum Rm, amplitude A_l and frequencies ω_l, and requires the computation of the second derivative of the frequency response $W''(m)$, -whereby the parameter λ_1 allows to switch between different optimization methods and the parameter λ_2 regularizes the system matrix.

10. A method according to any of claim 1 to 9, further comprising the step of computing the polynomial complex amplitudes by solving the equation given in Eq. (55),

$$\begin{bmatrix} \mathbf{B}^{1,1} & \mathbf{B}^{1,2} \\ \mathbf{B}^{2,1} & \mathbf{B}^{2,2} \end{bmatrix} \begin{bmatrix} \mathbf{A}^1 \\ \mathbf{A}^2 \end{bmatrix} = \begin{bmatrix} \mathbf{C}^1 \\ \mathbf{C}^2 \end{bmatrix} \quad (55)$$

using Eq. (63)

$$\begin{aligned}
B^{1,1}_{lP+q,kP+p} &= \frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{-q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k-\omega_l} \\
B^{1,2}_{lP+q,kP+p} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k+\omega_l} - (-1)^{q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k-\omega_l} \\
B^{2,1}_{lP+q,kP+p} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Im[Y(m)]\right]_{m=\omega_k-\omega_l} \\
B^{2,2}_{lP+q,kP+p} &= -\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k+\omega_l} + (-1)^{-q}\frac{1}{2}\left[\frac{\partial^{p+q}}{\partial m^{p+q}}\Re[Y(m)]\right]_{m=\omega_k-\omega_l} \\
C^1_{lP+q} &= \Re\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m \frac{\partial^q}{\partial m^q} W(m+\omega_l)\right) \\
C^2_{lP+q} &= -\Im\left(\frac{1}{N}\sum_{m=0}^{N-1} X_m \frac{\partial^q}{\partial m^q} W(m+\omega_l)\right) \\
A^1_{kP+p} &= A^r_{k,p} \\
A^2_{kP+p} &= A^i_{k,p} \qquad (63)
\end{aligned}$$

such that only the elements around the diagonal of $\mathbf{B}$ are taken into account, whereby a shifted form $\overleftarrow{\mathbf{B}}$ is computed containing only PD diagonal bands of $\mathbf{B}$ according to Eq. (64)

$$\begin{aligned}
\overleftarrow{B^{1,1}}_{lP+q,kP+p} &= B^{1,1}_{lP+q,lP+q+kP+p-(D+1)P+1} = B^{1,1}_{lP+q,(k+l-D)P+(p+q-P+1)} \\
\overleftarrow{B^{2,2}}_{lP+q,kP+p} &= B^{2,2}_{lP+q,lP+q+kP+p-(D+1)P+1} = B^{2,2}_{lP+q,(k+l-D)P+(p+q-P+1)} \qquad (64)
\end{aligned}$$

and Eq. (63), whereby the computation is required of the frequency response of the square window and its derivatives $\frac{\partial^p}{\partial m^p}Y(m)$ whereby the computation is required of the frequency response of the window and its derivatives $\frac{\partial^p}{\partial m^p}W(m)$, and solving the equation given by Eq. (55) directly from $\overleftarrow{\mathbf{B}}$ and $\mathbb{C}$ by an adapted gaussian elimination procedure.

11. A method according to any of claim 1 to 10, further comprising the step of computing instantaneous frequencies and instantaneous amplitudes according to Eq. (69),

$$\Psi_k(n) = \sqrt{\left(\sum_{p=0}^{P-1} \hat{A}^r_{k,p}(-2\pi\tfrac{n-n_0}{N})^p\right)^2 + \left(\sum_{p=0}^{P-1} \hat{A}^i_{k,p}(-2\pi i\tfrac{n-n_0}{N})^p\right)^2}$$
$$\Phi_k(n) = 2\pi i\omega_k \tfrac{n-n_0}{N} + i\arctan\left(\frac{\sum_{p=0}^{P-1} \hat{A}^i_{k,p}(-2\pi\frac{n-n_0}{N})^p}{\sum_{p=0}^{P-1} \hat{A}^r_{k,p}(-2\pi i\frac{n-n_0}{N})^p}\right) \qquad (69)$$

whereby the instantaneous frequency can be used as a frequency estimate for the next iteration as expressed in Eq. (73)

$$\omega_k^{(r+1)} = \omega_k^{(r)} - (\tfrac{1}{N})\frac{\hat{A}^r_{k,0}\hat{A}^i_{k,1} - \hat{A}^i_{k,0}\hat{A}^r_{k,1}}{\hat{A}^i_{k,0}{}^2 + \hat{A}^r_{k,0}{}^2} \qquad (73)$$

12. A method according to any of claim 1 to 11, further comprising the step of computing damping factor according to Eq. (78),

$$\rho_k \approx -(\tfrac{2\pi}{N})\frac{\hat{A}^r_{k,0}\hat{A}^r_{k,1} + \hat{A}^i_{k,0}\hat{A}^i_{k,1}}{\hat{A}^i_{k,0}{}^2 + \hat{A}^r_{k,0}{}^2} \qquad (78)$$

in case that the amplitudes are exponentially damped.

13. A method according to any of claims 1 to 12 the frequency response of the window with length M zero padded up to a length N is computed using a scaled table look-up according to Eq. (82)

$$\frac{N'}{N} w_{M'}^{N'}(n - n_0') = \frac{1}{N}\sum_{m=0}^{N'-1} W^M(\frac{M'}{N'}m - m_0)\exp(2\pi i\frac{(n-n_0')(m-m_0)}{N'}) \qquad (82)$$

14. Apparatus adapted to carry out each and every step of the method according to any of the previous claims 1 to 13.

15. Use of a method according to any of the claims 1 to 13 for accurate pitch estimation

16. Use of an apparatus according to claim 14 for accurate pitch estimation.

17. Use of a method according to any of the claims 1 to 13 for arbitrary sample rate conversion.

18. Use of an apparatus according to claim 14 for arbitrary sample rate conversion.

19. Use of a method according to any of the claims 1 to 13 for parametric/sinusoidal audio coders, where the noise residual, amplitudes and frequencies are encoded in a bitstream which is stored, broadcasted or transmitted at the sender side, the receiver decodes the bitstream back to the parameters and synthesizes the sound

20. Use of an apparatus according to claim 14 for parametric/sinusoidal audio coders, where the noise residual, amplitudes and frequencies are encoded in a bitstream which is stored, broadcasted or transmitted at the sender side, the receiver decodes the bitstream back to the parameters and synthesizes the sound.

21. Use of a method according to any of the claims 1 to 13 for audio effects whereby the noise r_n, the amplitudes $\bar{A}$ and frequencies $\bar{\omega}$ are manipulated by an effects processor yielding r_n^*, $\bar{A}^*$ and $\bar{\omega}^*$ and synthesized with these modified parameters.

22. Use of an apparatus according to claim 14 for audio effects whereby the noise r_n, the amplitudes $\bar{A}$ and frequencies $\bar{\omega}$ are manipulated by an effects processor yielding r_n^*, $\bar{A}^*$ and $\bar{\omega}^*$ and synthesized with these modified parameters.

23. Use of a method according to any of the claims 1 to 13 for source separation, whereby sinusoidal components originating from the same sound source are grouped and synthesized separately.

24. Use of an apparatus according to claim 14 for source separation, whereby sinusoidal components originating from the same sound source are grouped and synthesized separately.

25. Use of a method according to any of the claims 1 to 13 for automated annotation and transcription whereby the signal is segmented according to the values of the amplitudes and frequencies

26. Use of an apparatus according to claim 14 for automated annotation and transcription whereby the signal is segmented according to the values of the amplitudes and frequencies.